

Proton Decay Topical Working Group

13 Sep 2010



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LBNE

Fermilab

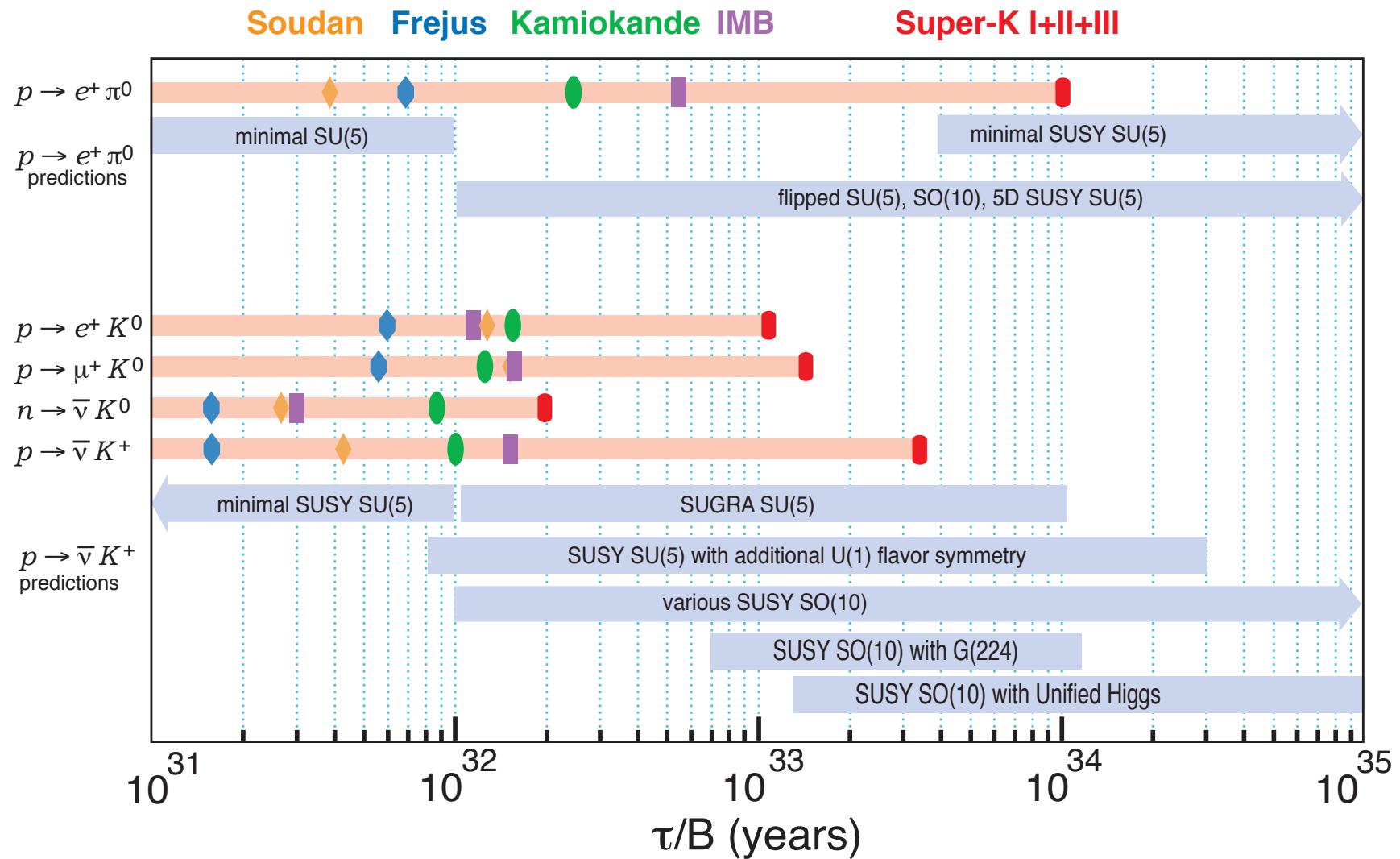
U.S. DEPARTMENT OF
ENERGY

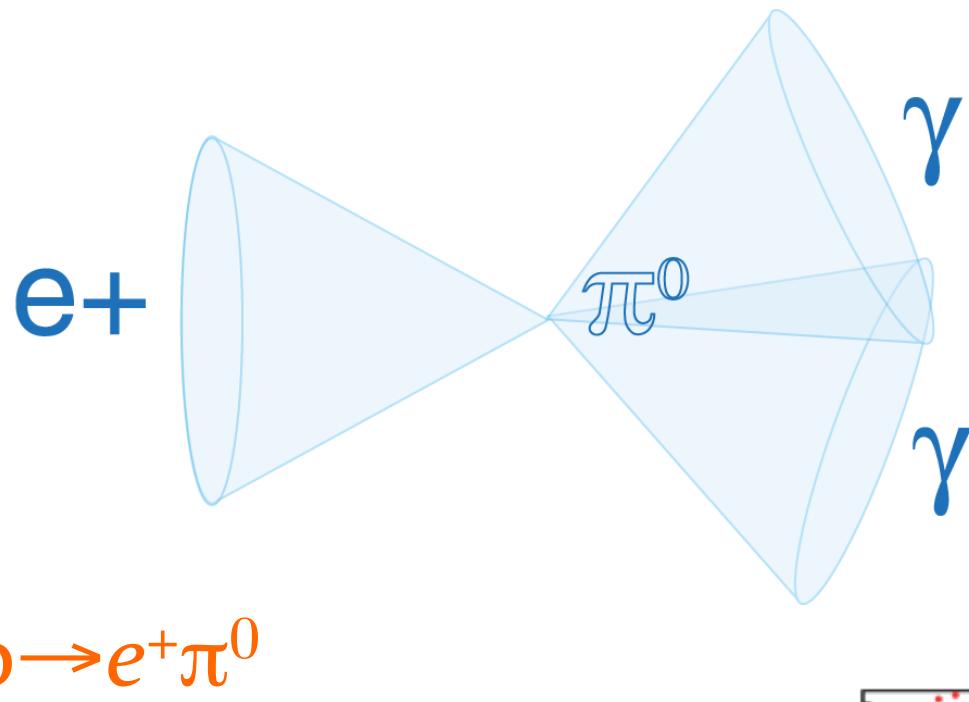
Scientific Impact of Proton Decay

- ❖ Tests a fundamental, but unexplained conservation law: baryon number.
- ❖ Grand Unified Theories make specific predictions: decay modes, lifetimes, branching ratios.
- ❖ Probes scales forever inaccessible to accelerators.
- ❖ New force carrying particles.
- ❖ Deep connections with other fields: cosmology, inflation, BAU, neutrino mass.
- ❖ Exotic connections with theory: strings, Planck scale, extra dimensions.
- ❖ Even if no signal, limits are very constraining on theory.

Theoretical Outlook

- ❖ Numerous and various models exist.
 - ❖ Lifetime predictions are not precise – typically uncertain by 2-3 orders of magnitude.
 - ❖ There are two favored and benchmark decay modes:
 $e^+\pi^0$ (gauge mediated) and νK^+ (SUSY D=5)
good for water good for LAr
 - ❖ There are other modes and processes: $\mu^+\pi^0$ (flipped), μ^+K^0 (SUSY), $\nu\pi^+$ and $\nu\pi^0$ (high BR but high background), among a total of 27 two-body antilepton+meson; also n-nbar, invisible modes, dinucleon decay, three-body B-L modes, B+L modes ...
 - ❖ Some theories suppress or exclude nucleon decay.



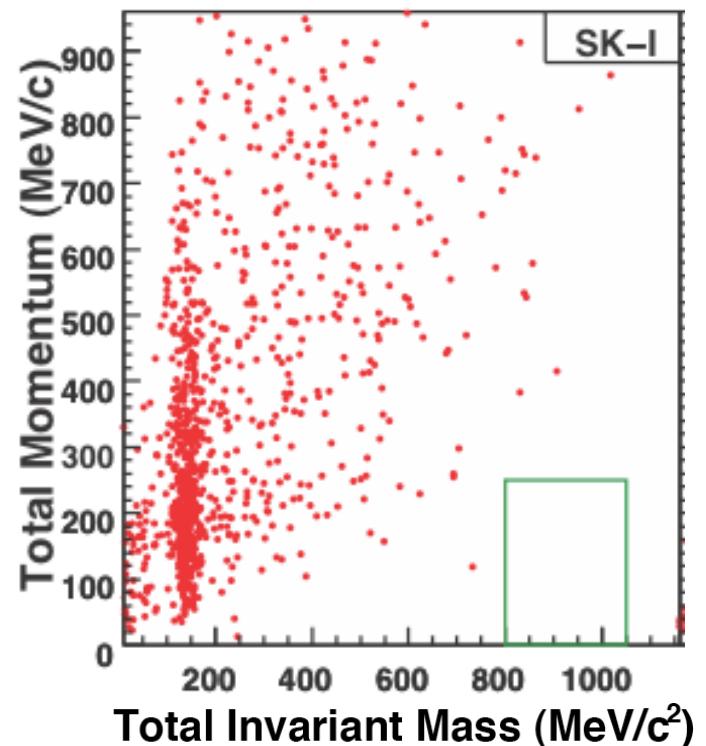


Simple signature: back-to-back reconstruction of EM showers

Efficiency ~45% dominated by nuclear absorption of π^0

Low background ~0.2 events/100 ktyr

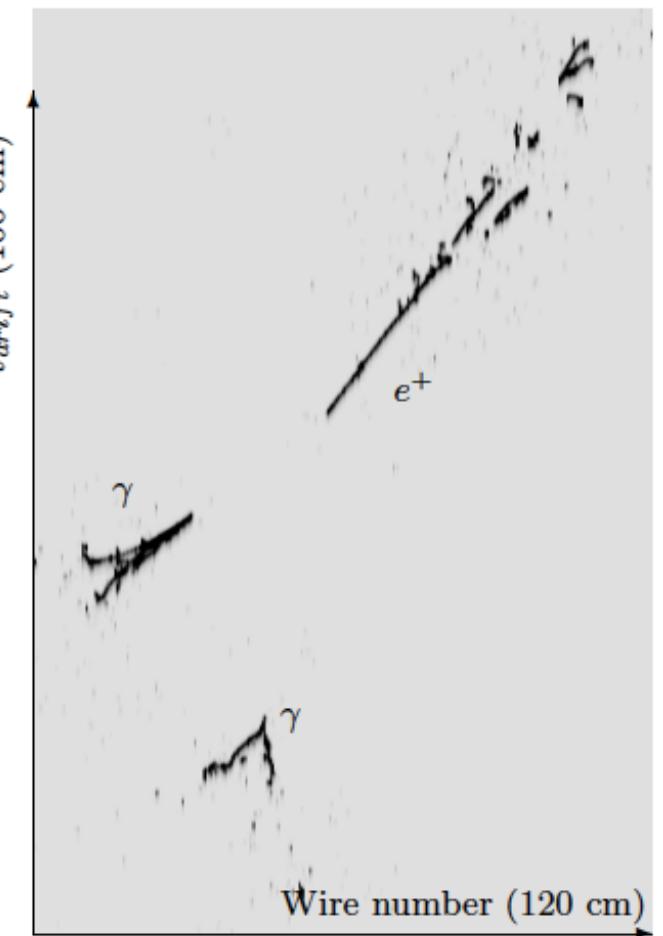
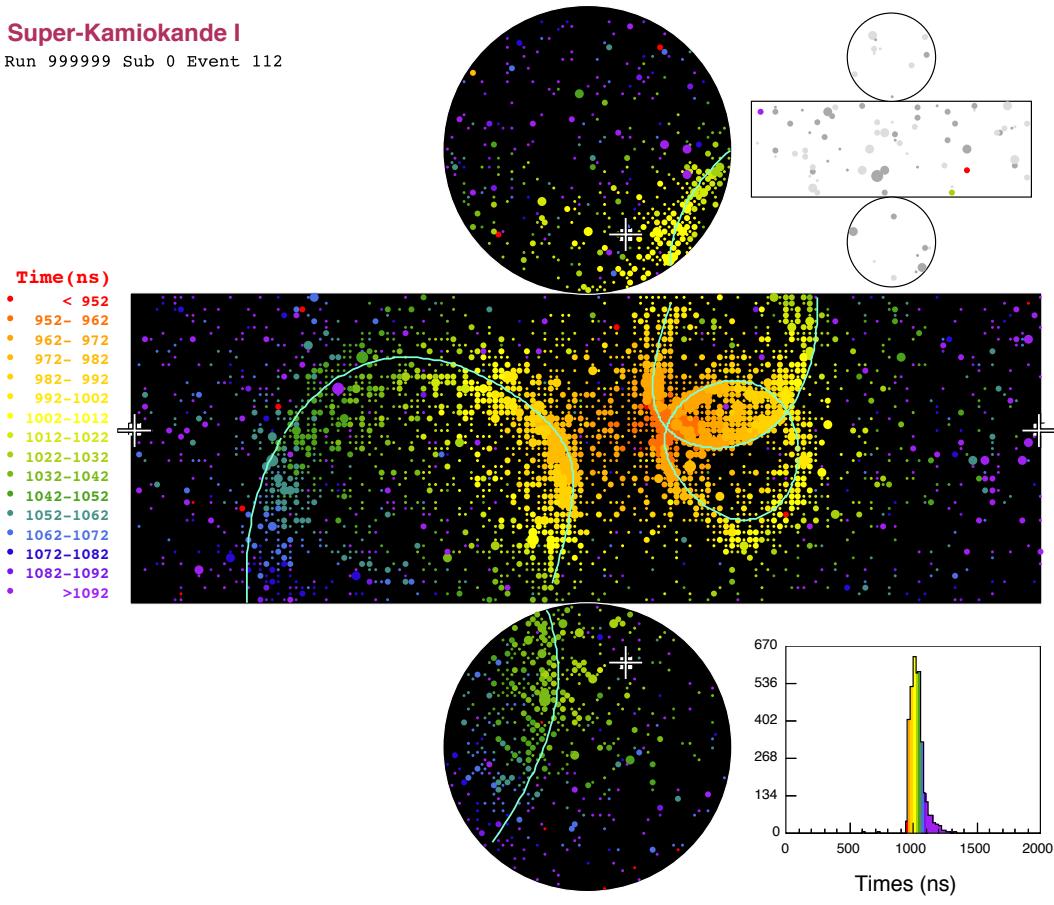
Relatively insensitive to PMT density.





A. Bueno et al. hep-ph/0701101

Super-Kamiokande I
Run 999999 Sub 0 Event 112



Key points:

WC - efficiency and background estimates nearly identical for SK1 and SK2

LAr - similar efficiency & background as water, but low mass makes it uncompetitive

WC Background Rate Discussion

❖ Current estimates

(/100 kton yr):

$0.21 \pm 0.03 \pm 0.08$

NEUT
(nuance similar)

$0.16 \pm 0.04 \pm 0.05$

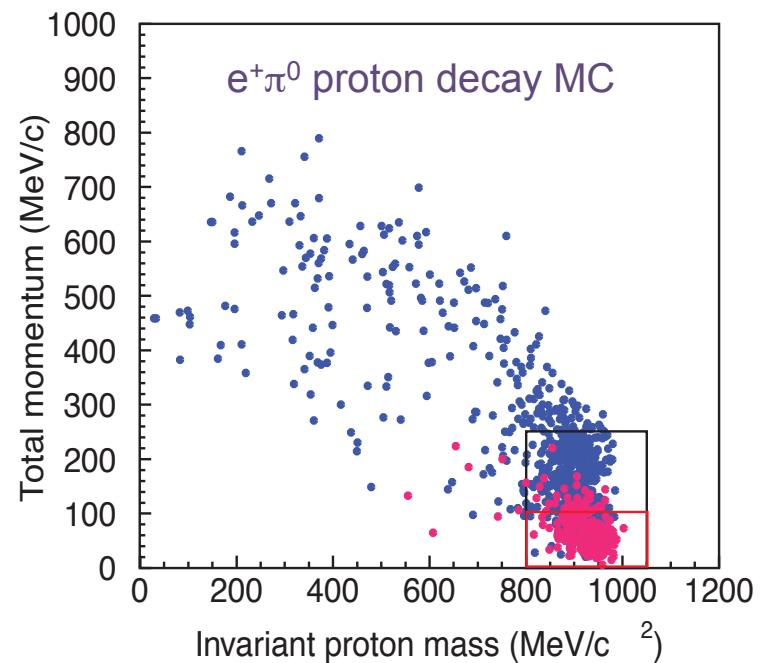
K2K 1KT
Near Detector

❖ Tight Cuts on Free Proton

- efficiency ~ 17%
- BG 0.015 evts/100 kton yr
- change over ~10-20 Mton yr

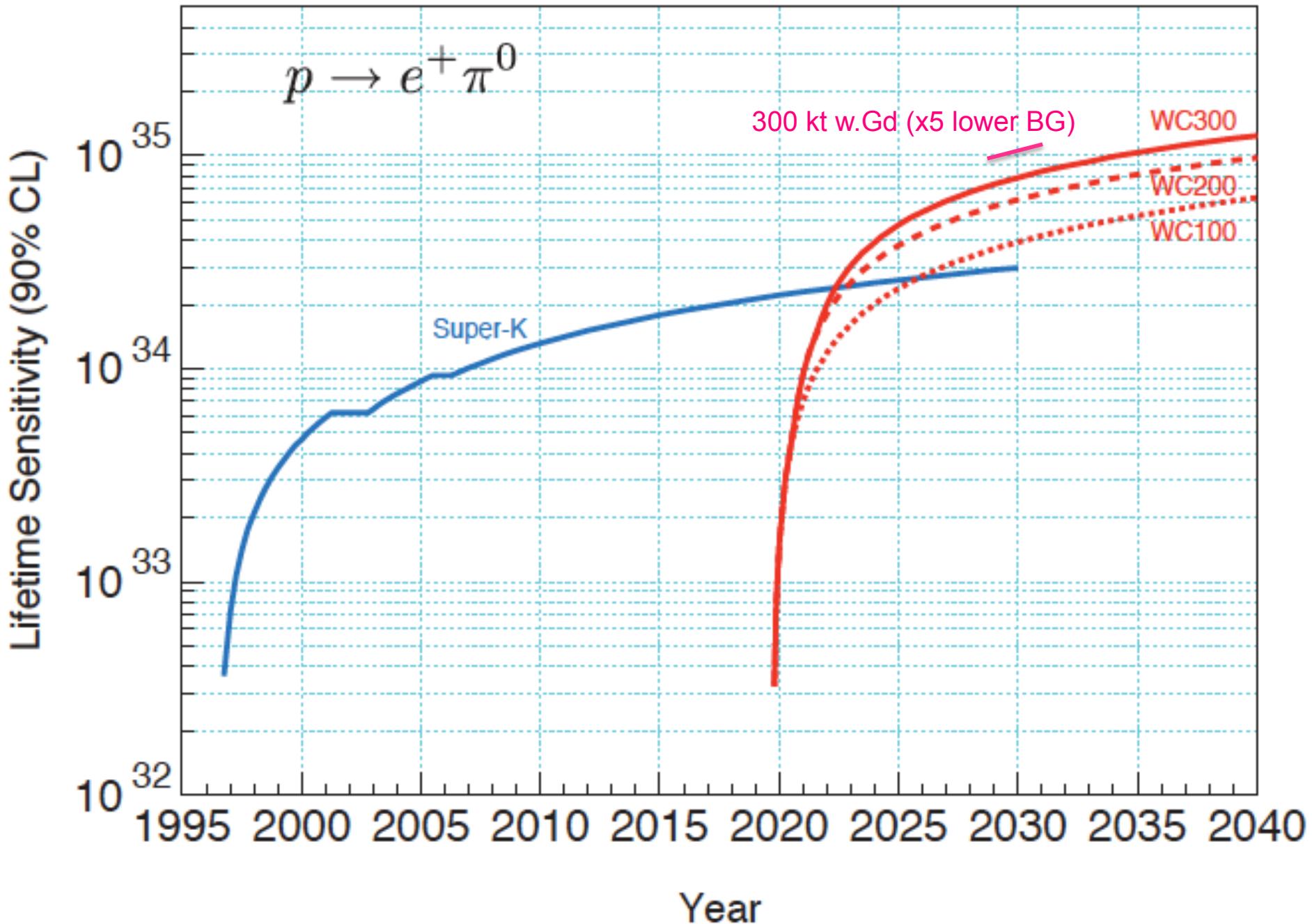
❖ Gadolinium

- high energy neutrino events are accompanied by n
- assume proton decay is not
- assume factor of 5 rejection (0.04 evts/100 kt yr)
- should be checked and studied
- N.B. argument “changes sign” from BG tag in SN relic analysis!



Background events for $p \rightarrow e^+ \pi^0$ (4.5 Megaton years)

	ν interactions	secondary interactions in water
1	$\nu n \rightarrow e^- p \pi^0$	Neutron production by the proton
2	$\nu p \rightarrow e^- p \pi^+$	Neutron by π^+
3	$\nu p \rightarrow e^- p (\pi^+) \pi^0$	
4	$\nu n \rightarrow \nu p \pi^- \pi^0$	
5	$\nu n \rightarrow e^- p$	Neutron by the proton
6	$\nu n \rightarrow e^- n \pi^+ \pi^-$	
7	$\nu p \rightarrow e^- p (\pi^+) \pi^0$	
8	$\nu p \rightarrow \nu p p$	
9	$\nu O \rightarrow e^- O \pi^+$	Neutron by π^+
10	$\nu n \rightarrow n p$	neutron and π^- by the neutron



Configuration	WC Mass	PMT	Gd	LAr Mass	WC BG evts	LAr BG evts	10-yr Limit ($\times 10^{34} \text{ yr}$)	Factor
1	300 kt	15%	N		6		8.2	2.7
1a	300 kt	30%	N		6		8.2	2.7
1b	300 kt	30%	Y		1.2		10.3	4.3
2				51 kt		0.51	2.6	0.9
2a				51 kt		0.51	2.6	0.9
2b				51 kt		0.51	2.6	0.9
3	200 kt	15%	N	17 kt	4	0.17	7.1	2.4
3a	200 kt	30%	N	17 kt	4	0.17	7.1	2.4
3b	200 kt	15%/30%	N/Y	17 kt	2.4	0.17	9.6	3.5
4	200 kt	15%	N	17 kt	4	0.17	7.1	2.4
4a	200 kt	30%	N	17 kt	4	0.17	7.1	2.4
4b	200 kt	15%/30%	N/Y	17 kt	2.4	0.17	9.6	3.5
5	100 kt	30%	Y	34 kt	0.4	0.34	7.0	2.3
6	100 kt	30%	Y	34 kt	0.4	0.34	7.0	2.3

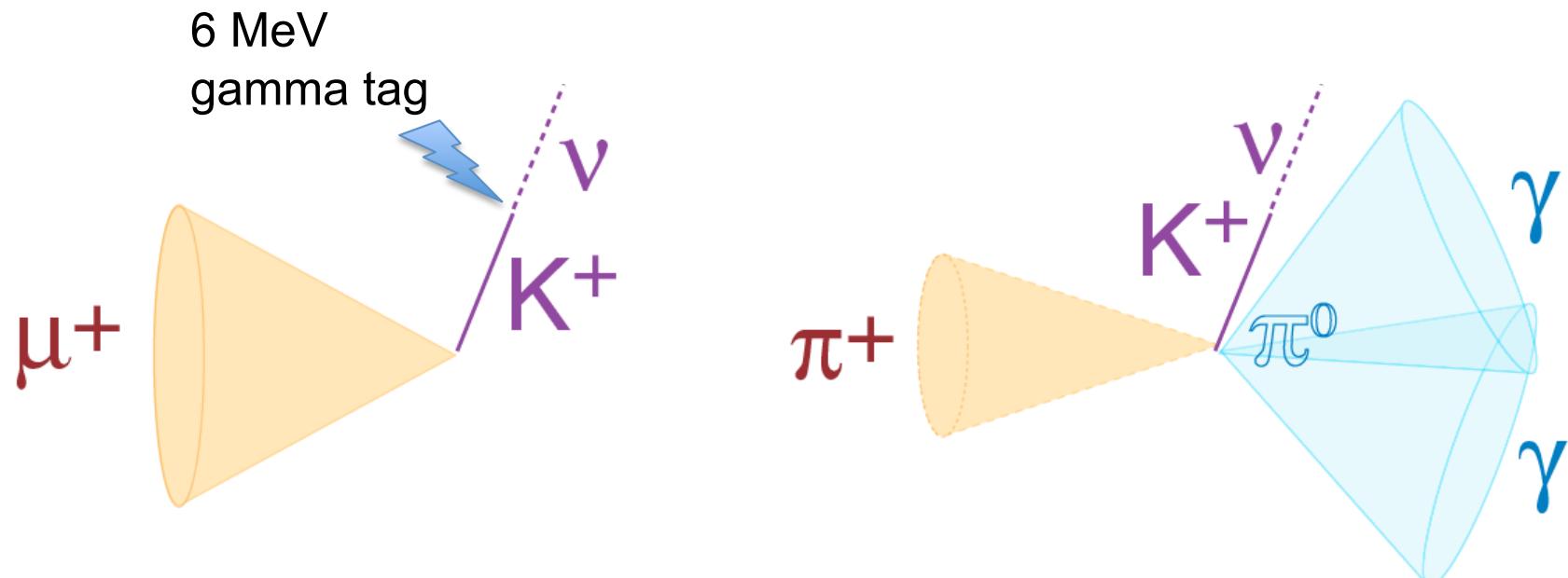
TABLE XIV. Summary of $p \rightarrow e^+ \pi^0$ proton decay results of the reference configurations (see Table III for more details). The background number of events and 90% C.L. limit is calculated assuming a 10-year exposure of the tabulated mass. Efficiencies and background rates are documented in the narrative. For hybrid configurations, the limits from WC and LAr are combined. The factor is compared to the projected Super-K limit in 2030 of 3×10^{34} years.

$$p \rightarrow K^+ \nu$$

Nuclear interaction is negligible

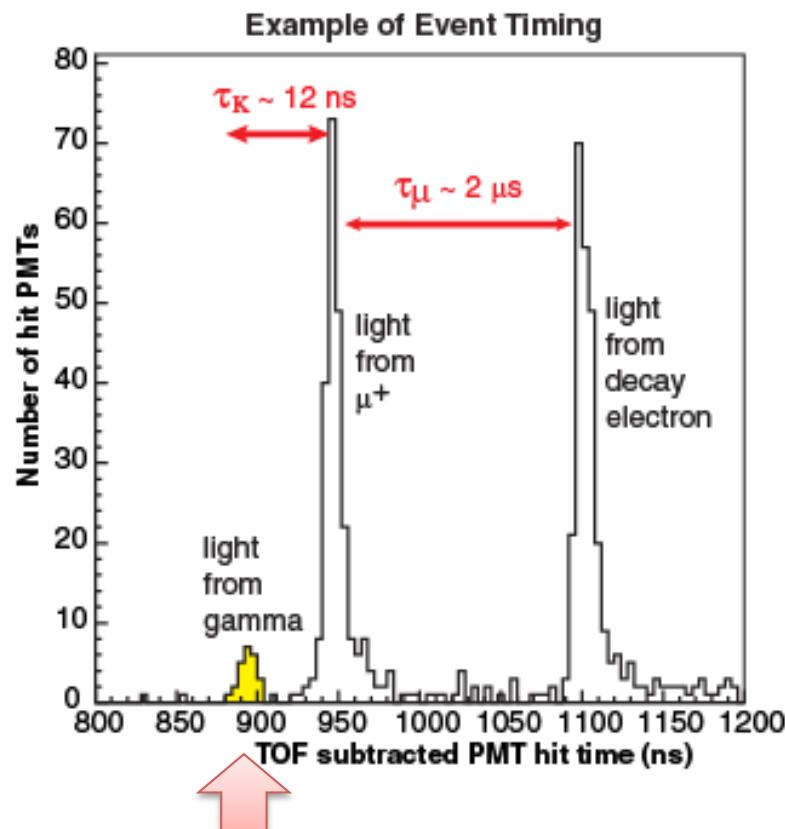
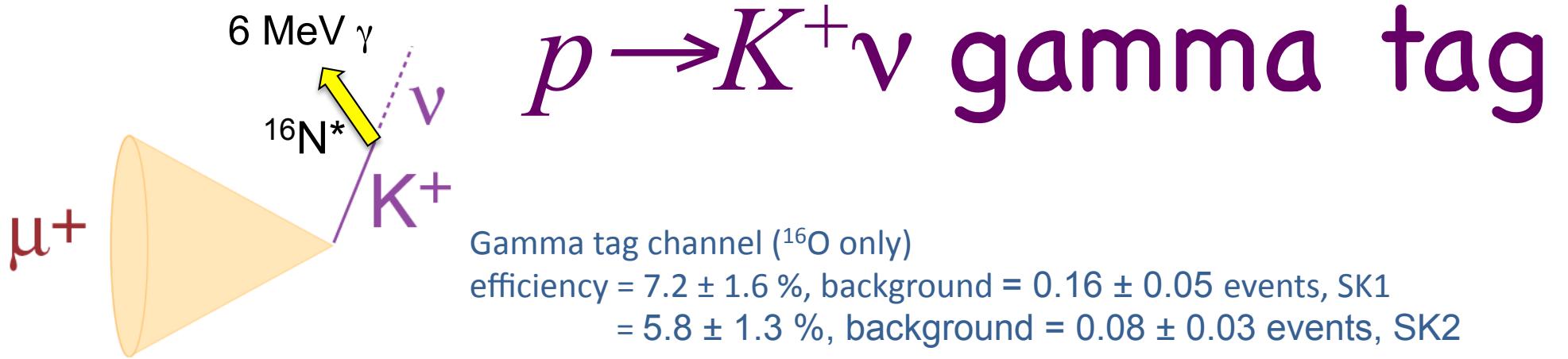
Kaon momentum is 340 MeV/c, below Cherenkov threshold
essentially a search for kaon decay at rest

$K^+ \rightarrow \pi^+ \pi^0$	21%
$K^+ \rightarrow \mu^+ \nu_\mu$	65%

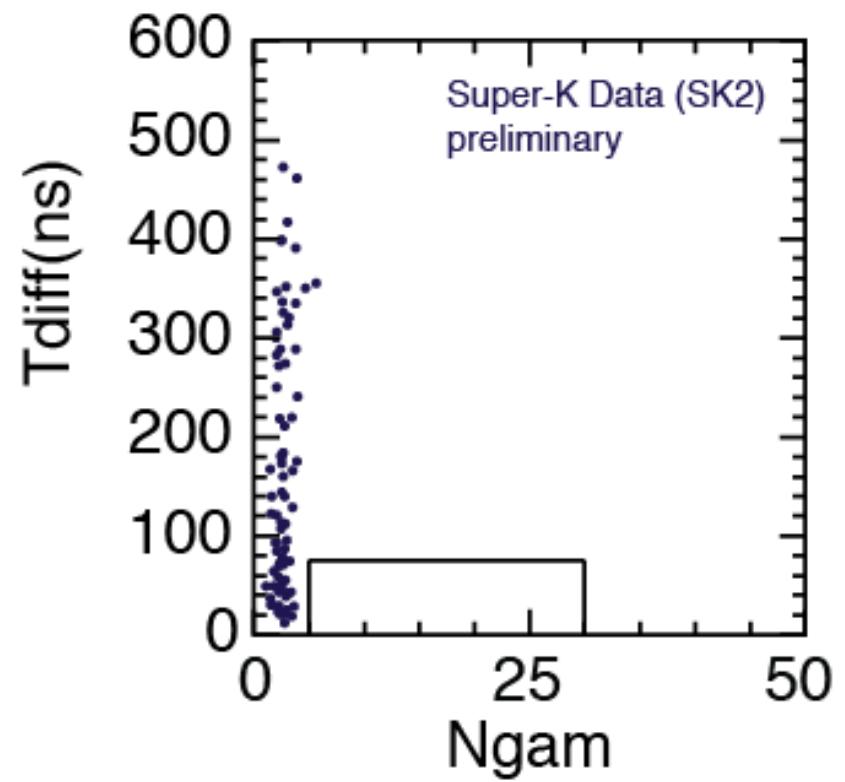


Combined efficiency ~14% dominated by detector reconstruction

Somewhat sensitive to PMT density. Efficiency for SK2 ~ 80% of efficiency for SK1

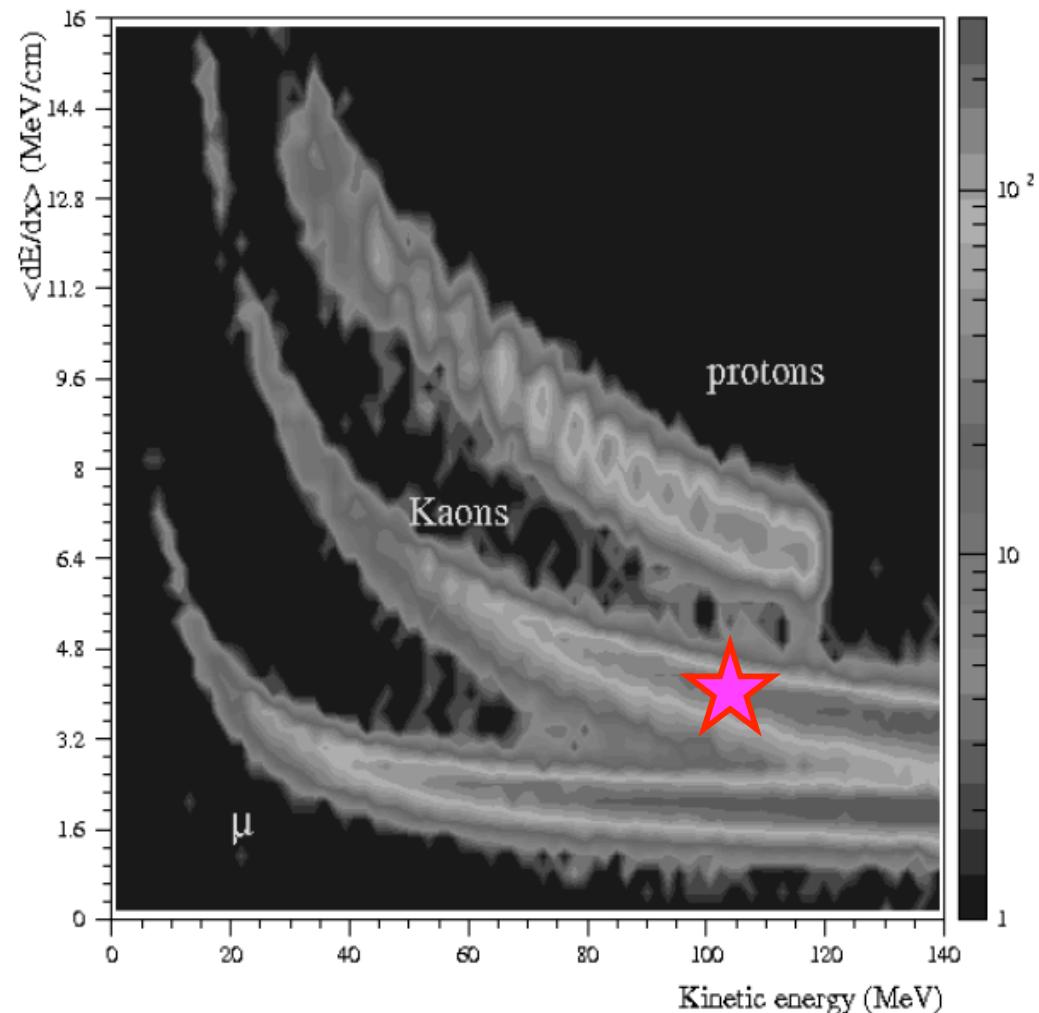
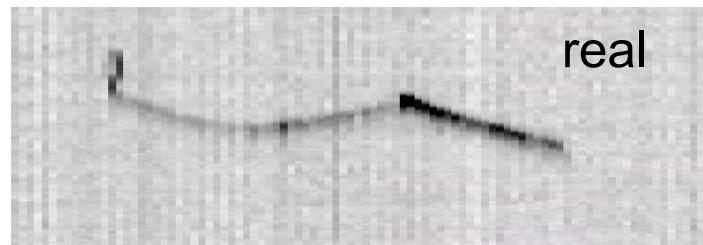
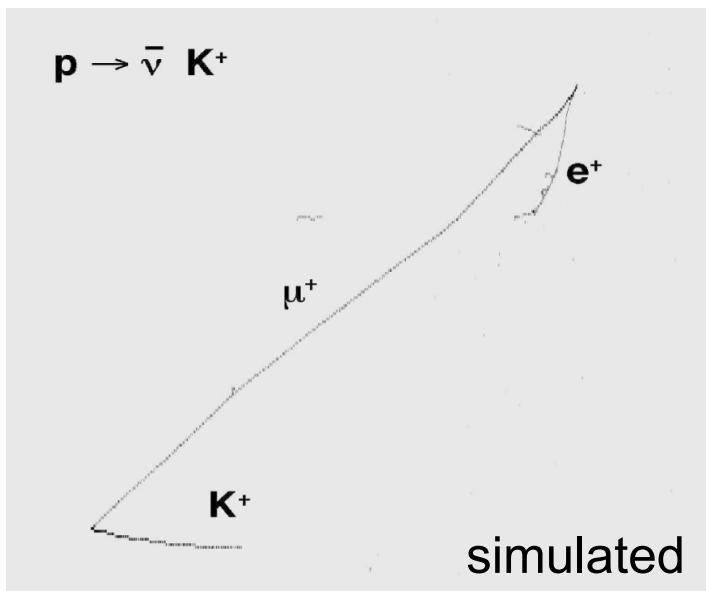


$8 < N_{\text{gam}} < 60$ (SK1)
 $4 < N_{\text{gam}} < 30$ (SK2)



no candidates in SK1 either

νK^+ in LAr

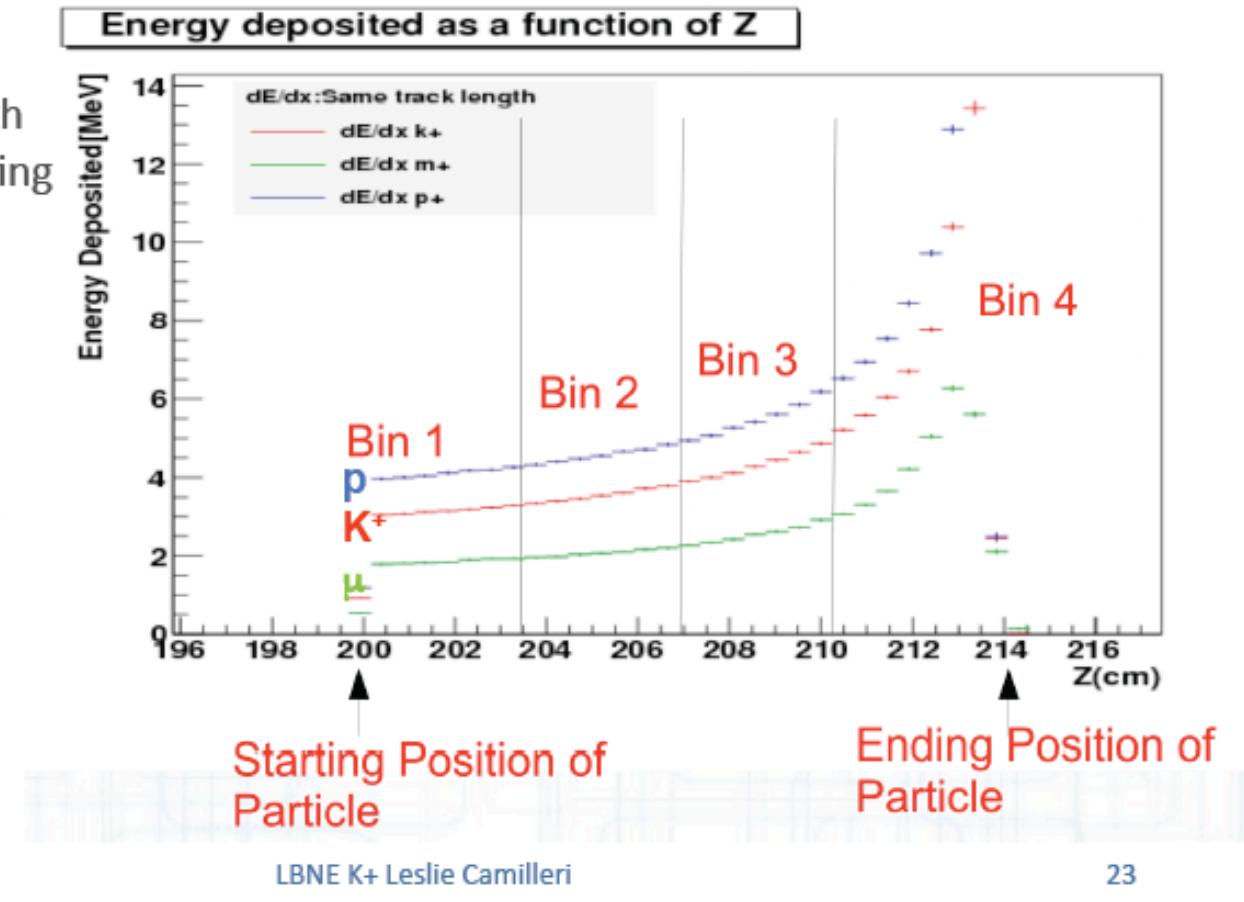


Cuts	(p3) $p \rightarrow K^+ \bar{\nu}$	ν_e CC	$\bar{\nu}_e$ CC	ν_μ CC	$\bar{\nu}_\mu$ CC	ν NC	$\bar{\nu}$ NC
One kaon	96.8%	308	36	871	146	282	77
No other charged tracks, no π^0	96.8%	0	0	0	0	57	9
$E_{vis} < 0.8$ GeV	96.8%	0	0	0	0	1	0

LAr Studies – MicroBooNE Group

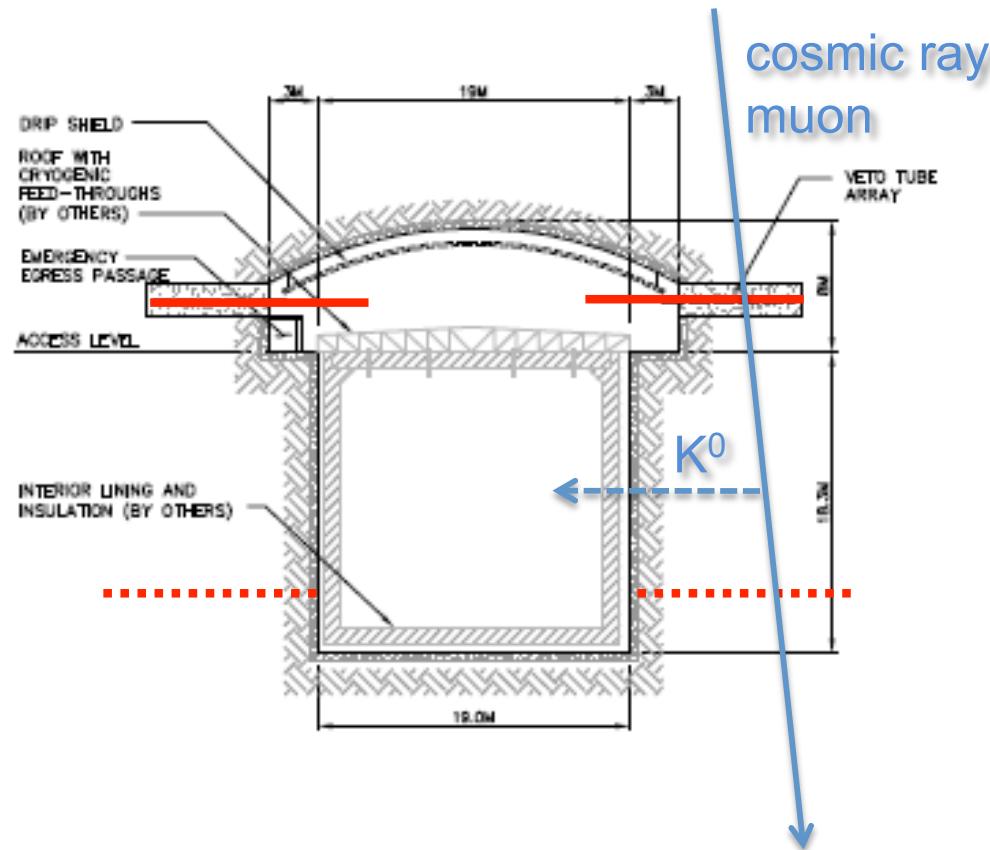
- ❖ K-select (topology) without photon/PMT trigger
- ❖ Entering K^0 background from cosmic ray interactions

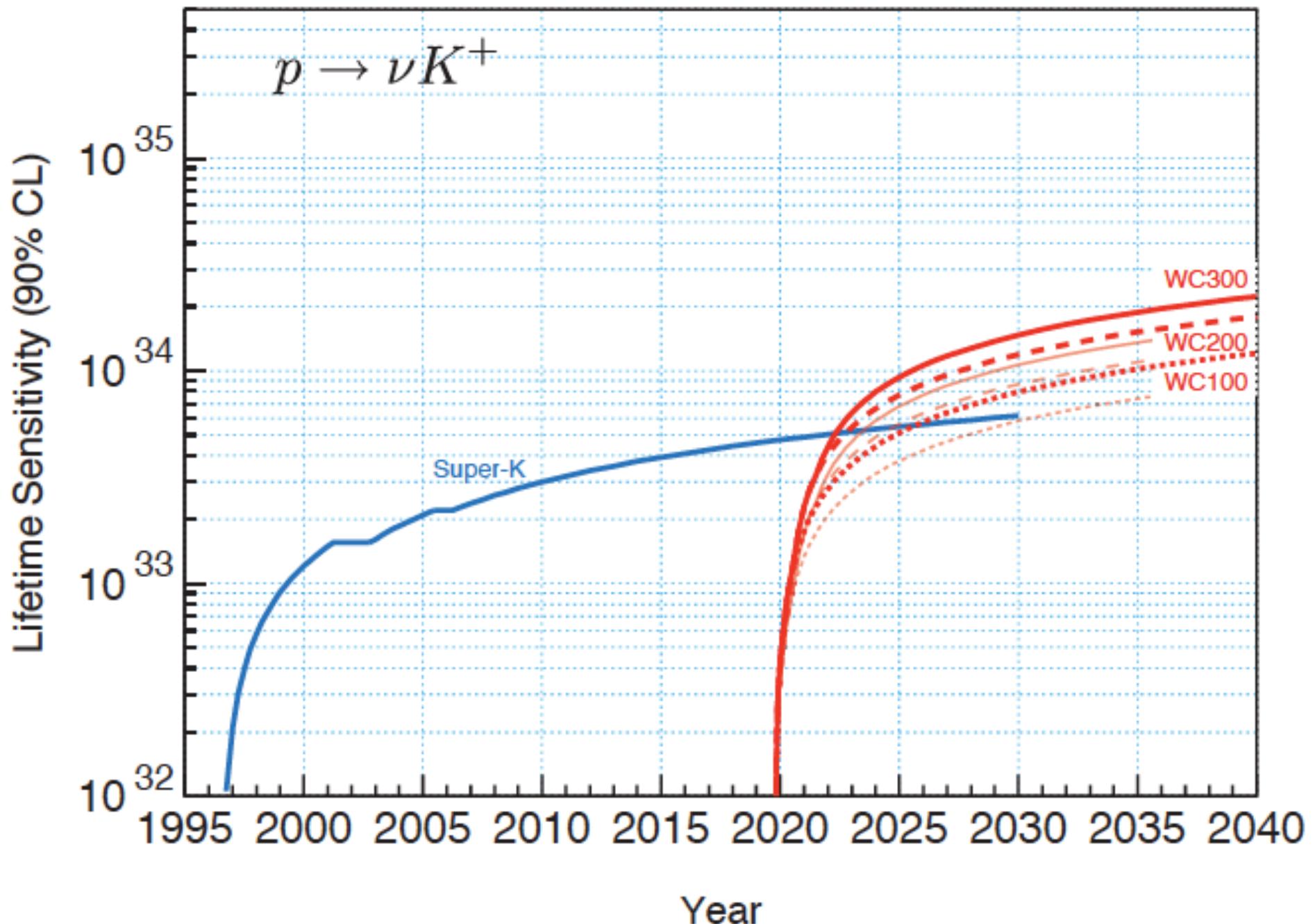
- ◆ We divided the track length into 3 Bins of 3.5 cm, starting at the stopping point.
- ◆ Summed the ionization in each of the 4 bins

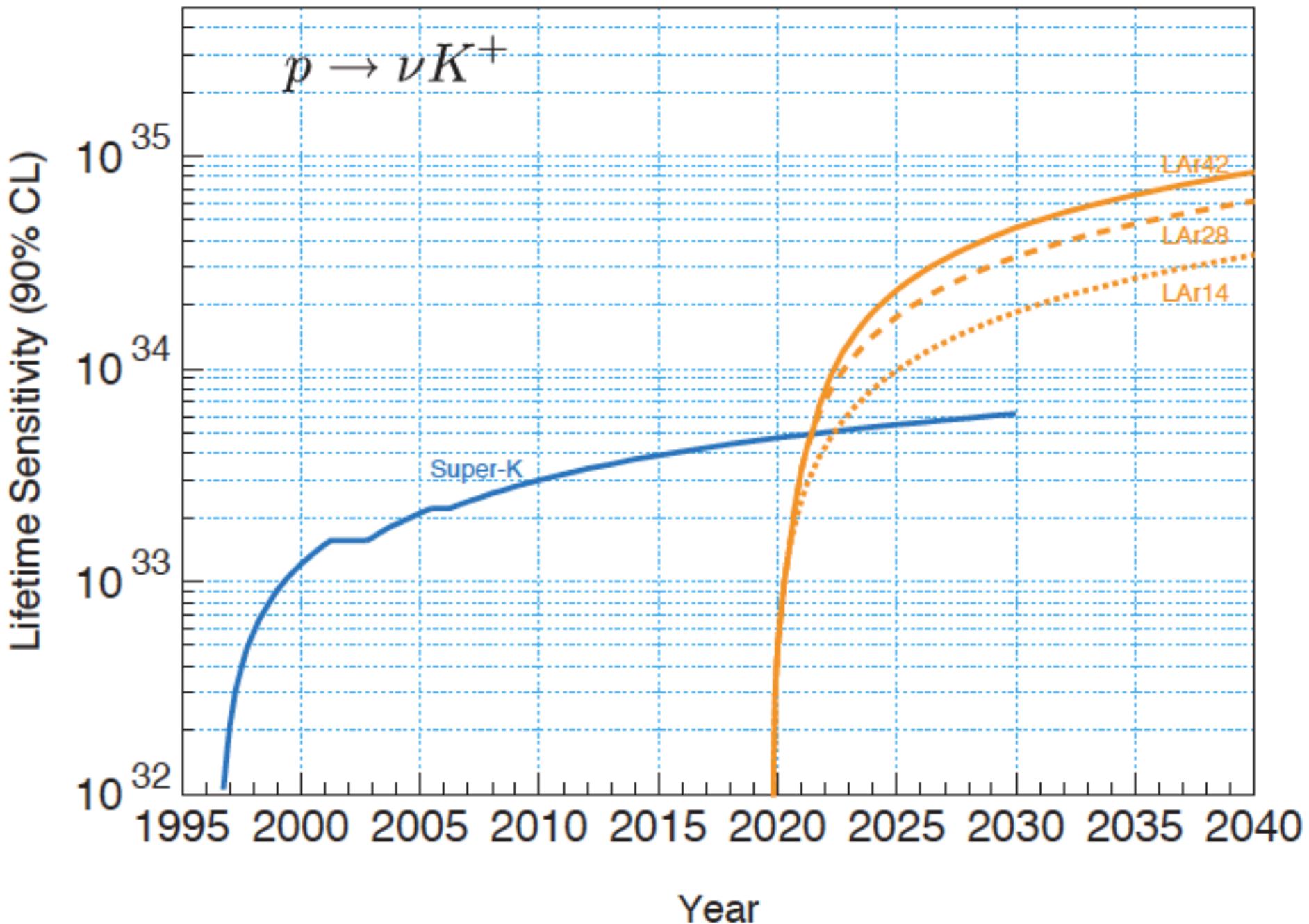


LAr Veto

- ❖ Background is entering K^0 with charge exchange from nearby cosmic ray interactions
- ❖ Assume that an active veto can be constructed to achieve a background rate reduction comparable to simply going to great depth
- ❖ Still require 1.8 m fiducial boundary for self-shielding
 - 20 kton detector with 17 kton FV will have 14 kton FV for νK^+ proton decay







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1b	300 kt	30%	Y		4		2.8	4.7
2				51 kt		0.51	5.7	9.5
2a				42 kt		0.42	4.8	8.0
2b				42 kt		0.42	4.8	8.0
3	200 kt	15%	N	14 kt	17	0.14	2.7	4.5
3a	200 kt	30%	N	14 kt	13	0.14	3.0	5.0
3b	200 kt	15%/30%	N/Y	14 kt	9	0.14	3.7	6.1
4	200 kt	15%	N	14 kt	17	0.14	2.7	4.5
4a	200 kt	30%	N	14 kt	13	0.14	3.0	5.0
4b	200 kt	15%/30%	N/Y	14 kt	9	0.14	3.7	6.1
5	100 kt	30%	Y	28 kt	1.3	0.28	4.7	7.8
6	100 kt	30%	Y	28 kt	1.3	0.28	4.7	7.8

TABLE XV. Summary of $p \rightarrow \nu K^+$ proton decay results of the reference configurations (see Table III for more details). The background number of events and 90% C.L. limit is calculated assuming a 10-year exposure of the tabulated mass. Efficiencies and background rates are documented in the narrative. For hybrid configurations, the limits from WC and LAr are combined. The factor is compared to the projected Super-K limit in 2030 of 0.6×10^{34} years.

Expected State of Knowledge

- ❖ Only one contemporary experiment (Super-K, 22.5 kton)
- ❖ Current exposure (SK 1+2+3) = 0.17 Mton yrs
- ❖ Total SK exposure circa 2018 = 0.4 Mton yrs
- ❖ Serious impact on the science case.
- ❖ Other projects? Hyper-K? Something out of LAGUNA?
LAr at Okinoshima?
- ❖ In-ocean ideas like TITAND? Too futuristic to worry.
- ❖ Expect little impact from theory.
- ❖ **Potential game-changer:** SUSY at the LHC.
- ❖ **Potential game-changer:** candidate events at Super-K.

Major Detector Related Questions

- ❖ WC: What is the impact of photocoverage?
 - ❖ Better timing of small tubes may help νK^+
- ❖ WC: Impact of Gd on atm. nu background reduction?
 - ❖ Validate factor of 5, study case for νK^+ BG.
- ❖ LAr: What is the impact of shallow depth?
 - ❖ Exposure loss due to C.R. muons
 - ❖ Background due to K^0 charge exchange (and neutrons?)
 - ❖ Validate assumptions used
- ❖ LAr: Is a photon-trigger needed?
- ❖ LAr: Can we generate by our own effort the high efficiency and low background estimates of Bueno paper?